WHAT IS CLAIMED AS NEW AND DESIRED TO BE SECURED BY LETTERS PATENT OF THE UNITED STATES IS:

1. A method for automated detection of lung nodules in computed tomography (CT) image scans, comprising:

generating two-dimensional segmented lung images by segmenting a plurality of two-dimensional CT image sections derived from said CT image scans;

generating three-dimensional segmented lung volume images by combining said two-dimensional segmented lung images;

determining three-dimensional lung nodule candidates from said three-dimensional segmented lung volume images, including, identifying structures within said three-dimensional segmented lung volume images that meet a volume criterion;

deriving features from said lung nodule candidates; and

detecting lung nodules by analyzing said features to eliminate false-positive nodule candidates from said nodule candidates.

2. The method of Claim 1, wherein said step of generating said segmented lung images comprises the steps of:

generating two-dimensional segmented thorax images by segmenting said plurality of two-dimensional CT image sections, including, applying gray-level thresholds to said CT image sections to determine thorax region contours therein; and

generating said two-dimensional segmented lung images by segmenting said segmented thorax images, including, applying gray-level thresholds to said segmented thorax images to determine said lung region contours therein.

3. The method of Claim 2, wherein said step of generating said segmented thorax images further comprises:

segmenting the trachea and main bronchi from said segmented thorax images using region growing.

4. The method of Claim 2, wherein said step of generating said segmented lung images further comprises:

segmenting the diaphragm from said segmented lung images using diaphragm analysis.

5. The method of Claim 1, wherein said step of generating said segmented lung volume images comprises:

generating said segmented lung images at a plurality of gray levels thresholds; and

combining said segmented lung images to generate segmented lung volume images at a plurality of gray levels corresponding to said grey level thresholds.

6. The method of Claim 5, wherein said step of identifying said structures comprises:

grouping a pixel from a given segmented lung image with one or more pixels therein, one or more pixels from a segmented lung image above said given segmented lung image and one or more pixels from a segmented lung image below said given segmented lung image to determine a structure;

performing said step of grouping at said plurality of grey level thresholds;

computing a volume of all determined structures at said plurality of grey level thresholds; and

determining said nodule candidates by comparing computed volumes of said determined structures at said plurality of gray levels with said volume criterion.

7. The method of Claim 6, further comprising:

using region erosion on said nodule candidates to determine if said nodule candidates comprise one or more smaller structures.

8. The method of Claim 1, wherein said step of deriving said features from said lung nodule candidates comprises one of:

applying a Hough transform in two or three dimensions on said identified structures to identify elongated or ellipsoidal nodule candidates having a high likelihood of corresponding to normal anatomy,

applying radial gradient index analysis in two or three dimensions on said identified structures to identify false-positive nodule candidates, and

applying similarity index analysis in two or three dimensions on said identified structures to compute a size of a nodule candidate relative to a distribution of sizes for neighboring nodule candidates; and

said step of detecting said lung nodules comprises analyzing at least one of said Hough transform, said radial gradient index and similarity index to eliminate said false-positive nodule candidates from said nodule candidates.

9. The method of Claim 8, wherein said step of applying radial gradient index analysis in two dimensions comprises:

obtaining contours in said segmented lung images for a plurality of gray-level increments,

treating each pixel location in a segmented lung image as a center of a potential nodule, and

calculating said radial gradient index (RGI) around each contour, where RGI is given by:

$$RGI = \left(\sum_{(x,\, y) \varepsilon M} \|\hat{G}(x,\, y)\| \right)^{-1} \sum_{(x,\, y) \varepsilon M} \hat{G}(x,\, y) \frac{\hat{r}(x,\, y)}{\|\hat{r}(x,\, y)\|}$$

where $\hat{G}(x, y)$ is a gradient vector of $f(x, y)$ at position (x, y) along a margin defined by a contour and $\hat{r}(x,y)/\|\hat{r}(x,y)\|$ is a normalized radial vector at said position (x, y); and

said step of detecting said lung nodules comprises comparing said radial gradient index to a predetermined threshold to eliminate said false-positive nodule candidates from said nodule candidates.

10. The method of Claim 8, wherein said step of applying radial gradient index analysis in three dimensions comprises:

obtaining surfaces in said segmented lung volume images for a plurality of gray-level increments,

treating each pixel location in a segmented lung volume image as a center of a potential nodule, and

calculating said radial gradient index (RGI) around each surface, where RGI is given by:

$$RGI = \left(\sum_{(x,\ y) \varepsilon M} \|\hat{G}(x,\ y)\| \right)^{-1} \sum_{(x,\ y) \varepsilon M} \hat{G}(x,\ y) \frac{\hat{r}(x,\ y)}{\|\hat{r}(x,\ y)\|}$$

where $\hat{G}(x, y)$ is a gradient vector of $f(x, y)$ at position (x, y) along a margin defined by a surface and $\hat{r}(x,y)/\|\hat{r}(x,y)\|$ is a normalized radial vector at said position (x, y); and

said step of detecting said lung nodules comprises comparing said radial gradient index to a predetermined threshold to eliminate said false-positive nodule candidates from said nodule candidates.

11. The method of Claim 8, wherein said step of applying similarity index analysis in two dimensions comprises:

determining contours in said in said segmented lung images,

determining zones within said contours, and

determining relative values of features of structures within said zones to discriminate between nodules and normal anatomy; and

said step of detecting said lung nodules comprises comparing said relative values of features of structures to predetermined thresholds to eliminate said false-positive nodule candidates from said nodule candidates.

12. The method of Claim 8, wherein said step of applying similarity index analysis in three dimensions comprises:

determining surfaces in said in said segmented lung volume images,

determining zones within said surfaces, and

determining relative values of features of structures within said zones to discriminate between nodules and normal anatomy, said features of structures including at least one of relative effective diameter, relative effective area, relative effective circularity and relative effective compactness; and

said step of detecting said lung nodules comprises comparing said relative values of features of structures to predetermined thresholds to eliminate said false-positive nodule candidates from said nodule candidates.

13. The method of Claim 8, wherein said step of deriving said features from said lung nodule candidates comprises:

determining features from said nodule candidates including at least one of structure volume, sphericity, radius of equivalent sphere, maximum compactness, maximum circularity, maximum eccentricity, mean gray level within structure, standard deviation of gray level and gray-level threshold at which structure volume first decreases below an upper volume bound; and

said step of detecting said lung nodules comprises one of:

using rule based analysis on said determined features to eliminate said false-positive nodule candidates from said nodule candidates, and

using an automated classifier on said determined features to eliminate said false-positive nodule candidates from said nodule candidates.

14. The method of Claim 13, wherein said step of using said automated classifier comprises using one of a linear discriminant analysis classifier and neural network classifier.

15. The method of Claim 1, wherein, prior to performing said step of generating said three-dimensional segmented lung volume images, a step of eliminating bright bands around a periphery of said two-dimensional segmented lung images using grey-level thresholding is performed.

16. A method for automated segmentation of lung regions from computed tomography (CT) image scans, comprising:

generating two-dimensional segmented lung images by segmenting a plurality of two-dimensional CT image sections derived from said CT image scans; and

generating three-dimensional segmented lung volume images by combining said two-dimensional segmented lung images;

wherein said step of generating said segmented lung images comprises the steps of:

generating two-dimensional segmented thorax images by segmenting said plurality of two-dimensional CT image sections, including, applying gray-level thresholds to said CT image sections to determine thorax region contours therein; and

generating said two-dimensional segmented lung images by segmenting said segmented thorax images, including, applying gray-level thresholds to said segmented thorax images to determine said lung region contours therein.

17. The method of Claim 16, wherein said step of generating said segmented thorax images further comprises:

segmenting the trachea and main bronchi from said segmented thorax images using region growing.

18. The method of Claim 16, wherein said step of generating said segmented lung images further comprises:

segmenting the diaphragm from said segmented lung images using diaphragm analysis.

19. The method of Claim 16, wherein, prior to performing said step of generating said three-dimensional segmented lung volume images, a step of eliminating bright bands around a periphery of said two-dimensional segmented lung images using grey-level thresholding is performed.

20. A method for automated segmentation of lung nodules in computed tomography (CT) image scans, comprising:

generating two-dimensional segmented lung images by segmenting a plurality of two-dimensional CT image sections derived from said CT image scans;

generating three-dimensional segmented lung volume images by combining said two-dimensional segmented lung images; and

determining three-dimensional lung nodule candidates from said three-dimensional segmented lung volume images, including, identifying structures within said three-dimensional segmented lung volume images that meet a volume criterion;

wherein said step of generating said segmented lung volume images comprises:

generating said segmented lung images at a plurality of gray levels thresholds; and

combining said segmented lung images to generate segmented lung volume images at a plurality of gray levels corresponding to said grey level thresholds.

21. The method of Claim 20, wherein said step of identifying said structures comprises:

grouping a pixel from a given segmented lung image with one or more pixels therein, one or more pixels from a segmented lung image above said given segmented lung image and one or more pixels from a segmented lung image below said given segmented lung image to determine a structure;

performing said step of grouping at said plurality of grey level thresholds;

computing a volume of all determined structures at said plurality of grey level thresholds; and

determining said nodule candidates by comparing computed volumes of said determined structures at said plurality of gray levels with said volume criterion.

22. The method of Claim 21, further comprising:

using region erosion on said nodule candidates to determine if said nodule candidates comprise one or more smaller structures.

23. The method of Claim 20, wherein, prior to performing said step of generating said three-dimensional segmented lung volume images, a step of eliminating bright bands around a periphery of said two-dimensional segmented lung images using grey-level thresholding is performed.

24. A method for automated detection of lung nodules in computed tomography (CT) image scans, comprising:

generating two-dimensional segmented lung images by segmenting a plurality of two-dimensional CT image sections derived from said CT image scans;

generating three-dimensional segmented lung volume images by combining said two-dimensional segmented lung images;

determining three-dimensional lung nodule candidates from said three-dimensional segmented lung volume images, including, identifying structures within said three-dimensional segmented lung volume images that meet a volume criterion;

deriving features from said lung nodule candidates; and

detecting lung nodules by analyzing said features to eliminate false-positive nodule candidates from said nodule candidates;

wherein said step of deriving said features from said lung nodule candidates comprises:

applying radial gradient index analysis in two or three dimensions on said identified structures to identify false-positive nodule candidates; and

said step of detecting said lung nodules comprises analyzing said radial gradient index to eliminate said false-positive nodule candidates from said nodule candidates.

25. The method of Claim 24, wherein said step of applying radial gradient index analysis in two dimensions comprises:

obtaining contours in said segmented lung images for a plurality of gray-level increments,

treating each pixel location in a segmented lung image as a center of a potential nodule, and

calculating said radial gradient index (RGI) around each contour, where RGI is given by:

$$RGI = \left(\sum_{(x,\, y) \varepsilon M} \|\hat{G}(x,\, y)\| \right)^{-1} \sum_{(x,\, y) \varepsilon M} \hat{G}(x,\, y) \frac{\hat{r}(x,\, y)}{\|\hat{r}(x,\, y)\|}$$

where $\hat{G}(x, y)$ is a gradient vector of $f(x, y)$ at position (x, y) along a margin defined by a contour and $\hat{r}(x,y)/\|\hat{r}(x,y)\|$ is a normalized radial vector at said position (x, y); and

said step of detecting said lung nodules comprises comparing said radial gradient index to a predetermined threshold to eliminate said false-positive nodule candidates from said nodule candidates.

26. The method of Claim 24, wherein said step of applying radial gradient index analysis in three dimensions comprises:

obtaining surfaces in said segmented lung volume images for a plurality of gray-level increments,

treating each pixel location in a segmented lung volume image as a center of a potential nodule, and

calculating said radial gradient index (RGI) around each surface, where RGI is given by:

$$RGI = \left(\sum_{(x,\ y)\varepsilon M} \|\hat{G}(x, y)\| \right)^{-1} \sum_{(x,\ y)\varepsilon M} \hat{G}(x, y) \frac{\hat{r}(x, y)}{\|\hat{r}(x, y)\|}$$

where $\hat{G}(x, y)$ is a gradient vector of $f(x, y)$ at position (x, y) along a margin defined by a surface and $\hat{r}(x,y)/\|\hat{r}(x,y)\|$ is a normalized radial vector at said position (x, y); and

said step of detecting said lung nodules comprises comparing said radial gradient index to a predetermined threshold to eliminate said false-positive nodule candidates from said nodule candidates.

27. The method of Claim 24, wherein, prior to performing said step of generating said three-dimensional segmented lung volume images, a step of eliminating bright bands

around a periphery of said two-dimensional segmented lung images using grey-level thresholding is performed.

28. A method for automated detection of lung nodules in computed tomography (CT) image scans, comprising:

generating two-dimensional segmented lung images by segmenting a plurality of two-dimensional CT image sections derived from said CT image scans;

generating three-dimensional segmented lung volume images by combining said two-dimensional segmented lung images;

determining three-dimensional lung nodule candidates from said three-dimensional segmented lung volume images, including, identifying structures within said three-dimensional segmented lung volume images that meet a volume criterion;

deriving features from said lung nodule candidates; and

detecting lung nodules by analyzing said features to eliminate false-positive nodule candidates from said nodule candidates;

wherein said step of deriving said features from said lung nodule candidates comprises:

applying similarity index analysis in two or three dimensions on said identified structures to compute a size of a nodule candidate relative to a distribution of sizes for neighboring nodule candidates; and

said step of detecting said lung nodules comprises analyzing said similarity index to eliminate said false-positive nodule candidates from said nodule candidates.

29. The method of Claim 28, wherein said step of applying similarity index analysis in two dimensions comprises:

determining contours in said in said segmented lung images,

determining zones within said contours, and

determining relative values of features of structures within said zones to discriminate between nodules and normal anatomy; and

said step of detecting said lung nodules comprises comparing said relative values of features of structures to predetermined thresholds to eliminate said false-positive nodule candidates from said nodule candidates.

30. The method of Claim 28, wherein said step of applying similarity index analysis in three dimensions comprises:

determining surfaces in said in said segmented lung volume images,

determining zones within said surfaces, and

determining relative values of features of structures within said zones to discriminate between nodules and normal anatomy, said features of structures including at least one of relative effective diameter, relative effective area, relative effective circularity and relative effective compactness; and

said step of detecting said lung nodules comprises comparing said relative values of features of structures to predetermined thresholds to eliminate said false-positive nodule candidates from said nodule candidates.

31. The method of Claim 28, wherein, prior to performing said step of generating said three-dimensional segmented lung volume images, a step of eliminating bright bands around a periphery of said two-dimensional segmented lung images using grey-level thresholding is performed.

32. A method for automated analysis of features of lung nodules in computed tomography (CT) image scans, comprising:

generating two-dimensional segmented lung images by segmenting a plurality of two-dimensional CT image sections derived from said CT image scans;

generating three-dimensional segmented lung volume images by combining said two-dimensional segmented lung images;

determining three-dimensional lung nodule candidates from said three-dimensional segmented lung volume images, including, identifying structures within said three-dimensional segmented lung volume images that meet a volume criterion; and

deriving features from said lung nodule candidates;

wherein said step of deriving said features from said lung nodule candidates comprises:

determining features from said nodule candidates including at least one of structure volume, sphericity, radius of equivalent sphere, maximum compactness, maximum circularity, maximum eccentricity, mean gray level within structure, standard deviation of gray level and gray-level threshold at which structure volume first decreases below an upper volume bound.

33. The method of Claim 32, further comprising:

using rule based analysis on said determined features to eliminate false-positive nodule candidates from said nodule candidates; and

using an automated classifier on said determined features to eliminate said false-positive nodule candidates from said nodule candidates.

34. The method of Claim 33, wherein said step of using said automated classifier comprises:

using one of a linear discriminant analysis classifier and neural network classifier.

35. The method of Claim 32, wherein, prior to performing said step of generating said three-dimensional segmented lung volume images, a step of eliminating bright bands around a periphery of said two-dimensional segmented lung images using grey-level thresholding is performed.

36. An image processing system configured to perform the steps recited in one of Claims 1 to 35.

37. A storage medium storing a program for performing the steps recited in one of Claims 1 to 35.